§14. Radiative Recombination of Xe^{10+} Ions

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In radiative recombination, a free electron is directly captured by a target, releasing its kinetic energy and binding energy of the final bound state to the emitted photon. Radiative recombination is an important contributor to the total recombination rate coefficients at least in some temperature ranges.

$$e + Xe^{10+}(4d^8) \rightarrow Xe^{9+}(4d^8\, nl) + \hbar\omega \qquad (1)$$

Radiative recombination is obtained from the photoionization cross sections through the Milne relation.

The photoionization cross sections for the n<10 shell are calculated in the distorted-wave approximation, taking into account the electronic dipole operator. The atomic code (FAC) used in the computation is developed by the M. F. Gu [1]. Photoionization cross sections are computed at six photon-electron energies of $E_e < 10E_{th}$, where the E_{th} values are the ionization thresholds for corresponding shells and for $E_e > 10E_{th}$, we used a simplified version of the formula suggested by Verner et al.[2] until 10000eV,

$$\sigma_{PI}(E_e) = \sigma_0 x^{-3.5-l+p/2}\left(\frac{1+b}{\sqrt{x}+b}\right)^p, \qquad (2)$$

where $x=(E_0+E_e)/E_0$, l is the orbital angular momentum of the photoionized shell, and σ_0, E_0, p, and b are fit parameters. For the photoionization of the particular *nl* shell, we obtained the radiative recombination to the excited state *nl*.

The radiative recombination cross section from FAC code are fitted by series of terms containing various powers of $u = E_e/E_{th}$ for $u \le 10$. For higher energies we need different fitting formula as Eq. (4).

$$\sigma_n^l(u) = \frac{1}{u(u+1)} \times \sum_{i=0}^{3} a_i u^i, \quad (u \le 10)\,[cm^2] \qquad (3)$$

$$\sigma_n^h(u) = \frac{1}{u(u+1)} \times 10^{\sum_{i=0}^{6} a_i u^i}, \quad (10 < u < 1000) \quad [cm^2] \qquad (4)$$

Here a_n is the fitting parameter. This cross section fitting formula is used until $n \le 10$ shell. Radiative recombination for n >10 shells are estimated using the semiclassical Kramers formula

$$\sigma_n(x) = 2.1 \times 10^{-22} \cdot \frac{n}{x(x+1)}, \quad x = E_e/E_0 \quad [cm^2] \qquad (5)$$

where n is the principle quantum number, $E_0 = z^2Ry/n^2$, Ry is the Rydberg energy, and z is the residual charge of the ion. Contributions up to n = 1000 are taken into account. The Maxwellian averaged rate coefficients of the partial *n* shells are calculated numerically using the cross sections in the temperature range 10^{-3} - 10^3 eV

$$K_{rr}^n(Te) = 6.6941 \times 10^{-14}\sqrt{E_{th}^n}\,\beta^{3/2} \times \left(\int_0^{10} u\,\sigma_n^l(u)\,e^{-\beta u} + \int_{10}^{\infty} u\,\sigma_n^h(u)\,e^{-\beta u}\right) \qquad (6)$$

where $\beta = E^n_{th}/kT_e$. Thus, the total radiative recombination rate coefficient into all states of the Xe^{9+} ions can be written in the form

$$K_{rr}^{tot}(T_e) = \sum_{n=4}^{10} K_{rr}^n(T_e) + \sum_{n=11}^{1000} 5.18 \times 10^{-14} \times z\beta'^{3/2} e^{-\beta'} E_1(\beta') \qquad (7)$$

where $\beta' = z^2Ry/n^2\,kT_e$.

Figure 1 show the *l*-distribution of radiative recombination rate coefficient at n=5. Figure 2 show the total radiative recombination rate coefficient represented by the solid line and the total dielectronic recombination rate coefficient represented by the dotted lines. Through figures, we know that the values of the radiative recombination rate coefficient are smaller than the values of the dielectronic recombination processes in our interest temperature region at Te = 1eV - 1000eV.

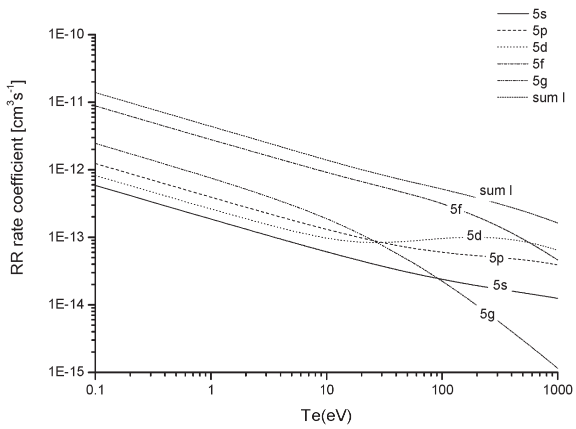

Fig. 1. *l*-distribution of radiative recombination rate coefficient at n=5.

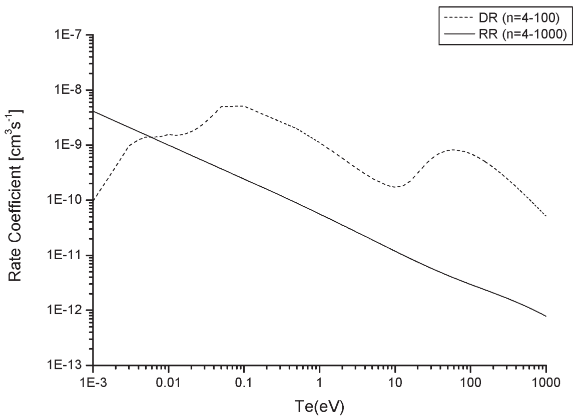

Fig. 2. Comparison of radiative recombination rate coefficient (the dotted line) and dielectronic recombination rate coefficient (the solid line) of Xe^{10+} ions.

Reference

1) M. F. Gu, Astrophys. J. **590** (2003) 1131
2) D. A. Verner, D. G. Yakovlev, I. M. Band, and M. B. Trzhaskovskaya, At. Data Nucl. Data Table, **55** (1993) 233